A CRITICAL ASSESSMENT OF THE SPECTRAL RESOLUTION NEEDED FOR THE CONSTELLATION-X MISSION: BREAKPOINTS

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WHEN A SPECTRUM IS NOT RESOLVED,
THE SYSTEMATIC ERRORS ARE UNKNOWN.

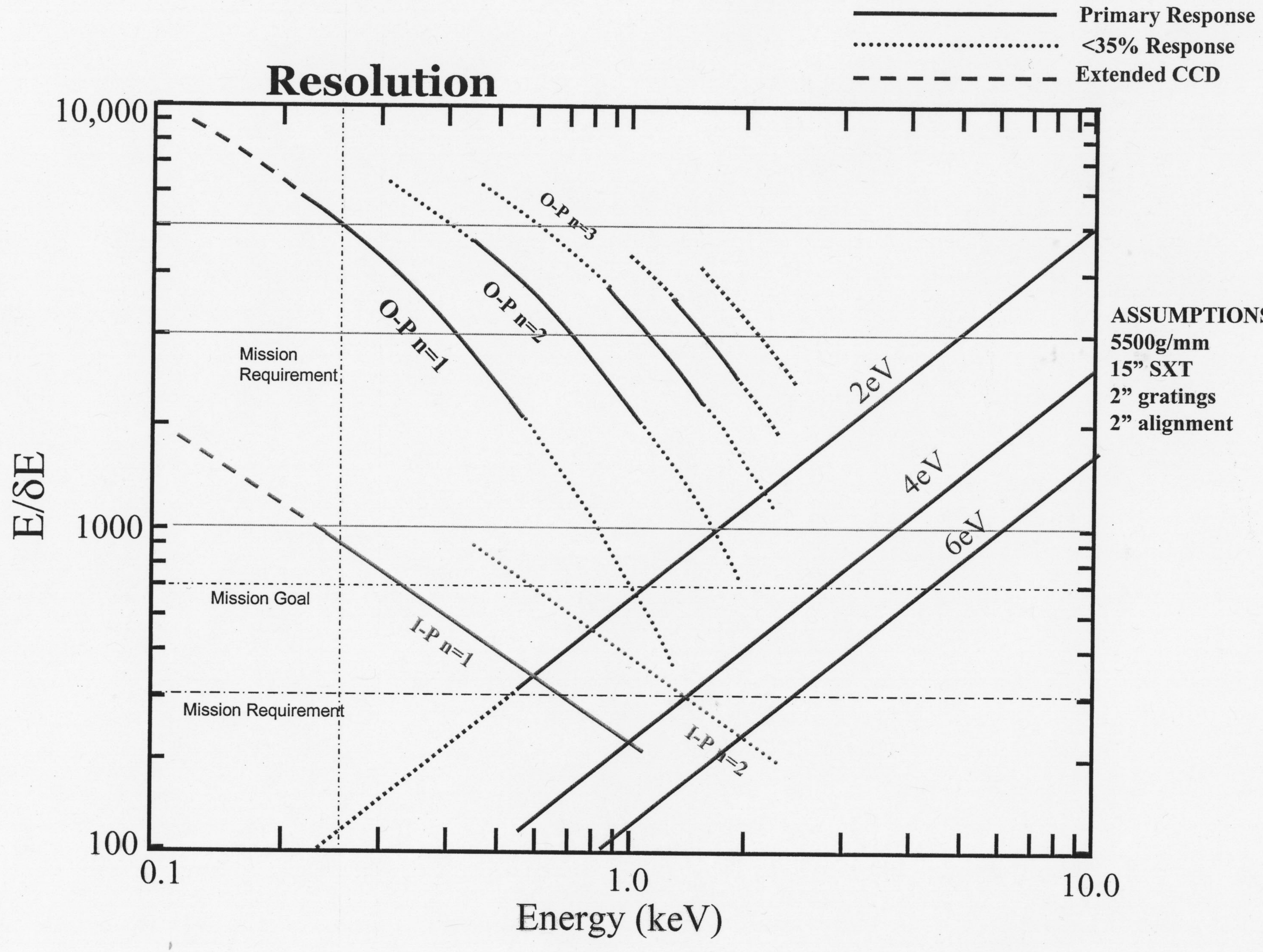
WHEN THE SYSTEMATIC ERRORS ARE UNKNOWN,
THE RANDOM ERRORS ARE IRRELEVANT.

IF YOU NEED HIGH RESOLUTION SPECTRA OF C IV, N V, O VI AND SI IV LINES TO INFER THE VELOCITY STRUCTURE ALONG THE LINE OF SIGHT,
REMEMBER THAT WHEN CON-X OPERATES,

- HST AND FUSE WILL BE LONG GONE
- THERE IS NO PLANNED HIGH RESOLUTION UV SPECTROGRAPH TO TAKE ITS PLACE.

GOOD LUCK!

Resolution



ASSUMPTIONS:
5500g/mm
15" SXT
2" gratings
2" alignment

SCIENCE ENABLED WITH INCREASING ENERGY RESOLUTION

Speaker	Resolution Require	Resolution Goal	Science Objectives
LOW RESOLUTION			
Paerels	500		Excitation mechanism (collisions or photoionization) in accretion sources (He-like triplets and recombination continua are the diagnostics). Higher resolution needed to resolve velocity fields.
MODERATE RESOLUTION			
Dewey	1,000	2,000	Bulk Doppler velocities in spatial sub-regions of SNRs to construct a 3–D model of the plasma.
Hughes	1,000		Velocities of SNRs, also need 5" spatial resolution.
Reeves	1,000	3,000	Separate the major emission/absorption K shell lines (6.7 keV) from Fe XVIII-XXV and resolve the He-like Fe XXV triplet (measures T, n_e) in AGN.
Brickhouse	1,000	$> 5,000$	Thermal line widths of collisionally-excited Fe L shell lines in stellar coronae and WHIM. Higher resolution needed for photoionized plasmas and Doppler imaging of stellar coronae.
Schulz	1,500		Galactic and extragalactic absorption line surveys at 0.5 keV (At 1 keV $> 1,000$ is OK).
Reynolds	(1,000)		Absorption lines produced in accretion disks of AGNs and XRBs.
HIGH RESOLUTION			
Shull	1,500	3,000	Shocks in the IGM seen in O VII and O VIII (separate velocity components at 200 km/s but a useful goal is 100 km/s).
Cohen	3,000	5,000	Velocity structure, spatial inhomogeneities, time variability, densities of OB star winds (lines at 0.5 to 1.5 keV).
Linsky	3,000	4,500	Dynamics and densities of stellar coronae (line blends, separation of lines from continuum).
Brickhouse Krongold Elvis	3,000	10,000	Measure the centroids of the different velocity components and identify the unsaturated lines in the warm absorber outflows from AGN
VERY HIGH RESOLUTION			
Nicastro	(5,000)		Resolve and measure the width of O VII forest lines toward Mkn 421.
Kaastra	10,000		Identify discrete components (30 km/s separations) in AGN absorption lines (lower resolution OK for AGN outflows).

1 How useful is high resolution spectroscopy?

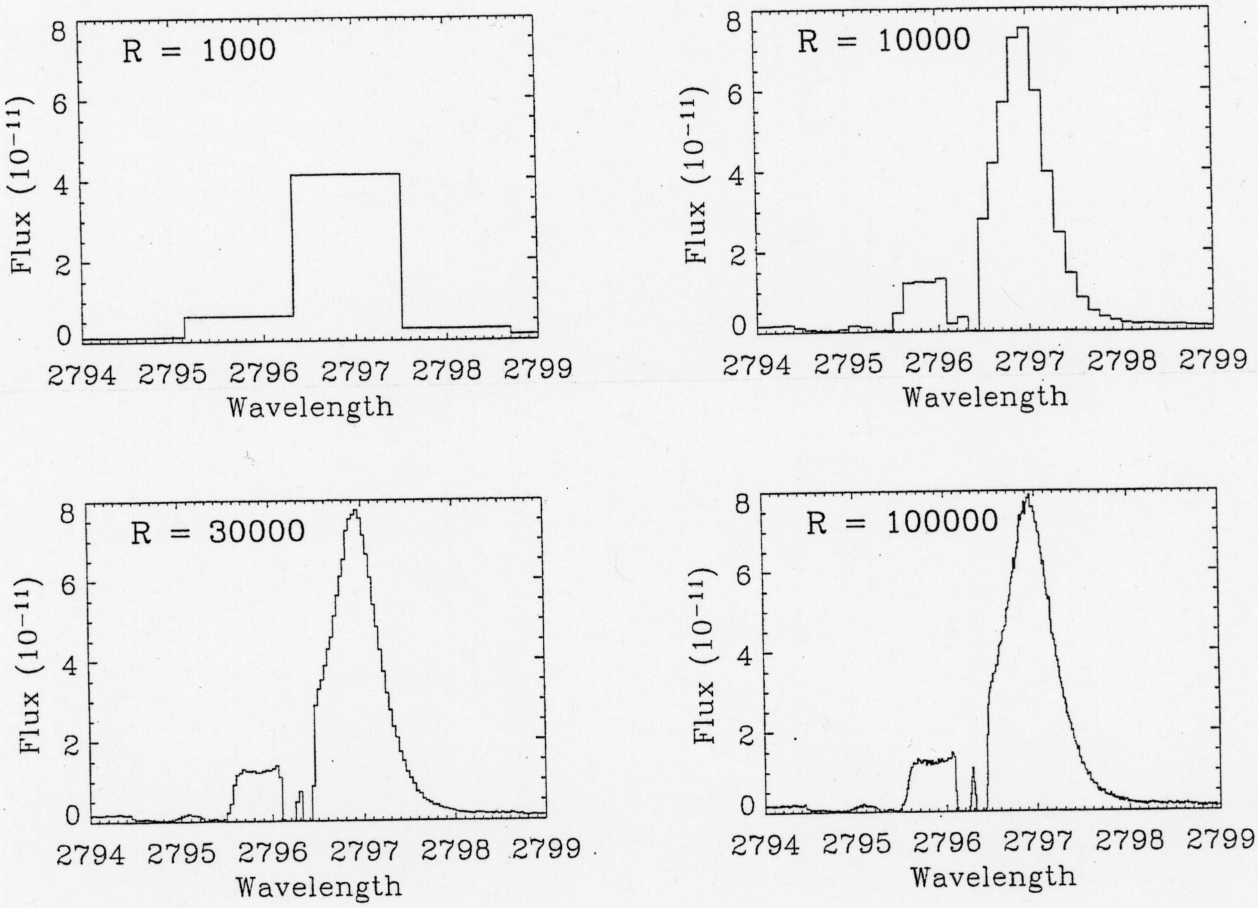
One can usually measure a physical parameter, but without sufficient energy resolution the systematic errors are unknown.

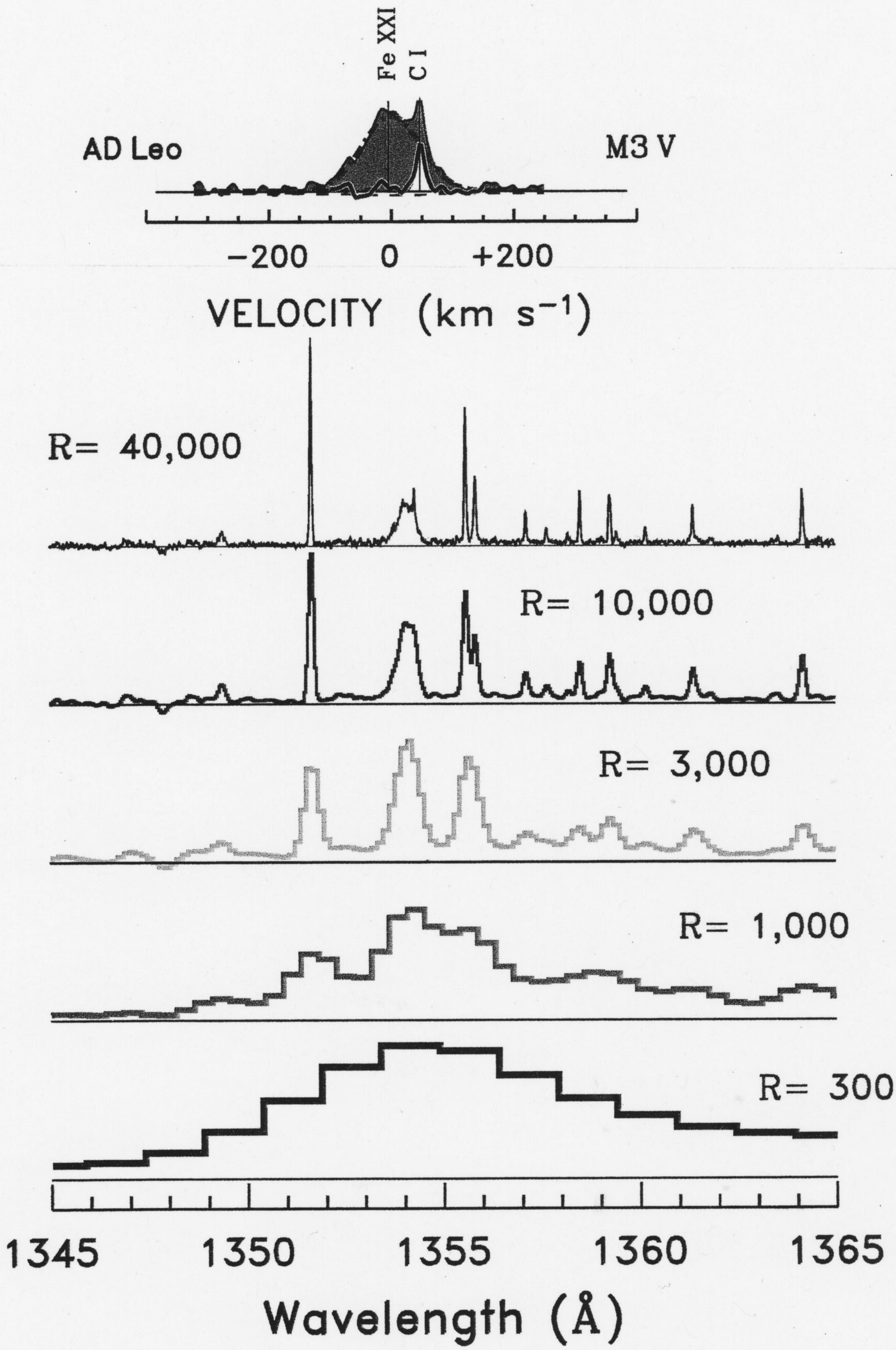
- Determine whether emission/absorption lines are blended, and accurately measure the component lines.
- Accurately separate the emission/absorption lines from the continuum and pseudocontinuum (grass).
- Measure the velocity structure along a line of sight.
- Measure column densities and line widths for saturated (optically thick) lines. Unresolved saturated velocity components lead to inaccurate column densities and line widths.

Two examples:

(1) **α TrA observed with STIS E230H:** Separately measure the emission line strength, two interstellar absorption lines, and the shape of the wind absorption. (See Figure 1.)

(2) **AD Leo observed with STIS E140M:** Separate the Fe XXI 1354.08 Å line from the C I 1354.288 Å line ($\Delta v = 46$ km/s), measure the Fe XXI line width and Doppler shift. (See Figure 2.)


R = 1000
R = 10000
R = 30000
R = 100000
Flux (10−11)
Wavelength
2794 2795 2796 2797 2798 2799
0 2 4 6 8



Fe XXI
C I
AD Leo
M3 V
−200
0
+200
VELOCITY (km s−1)
R= 40,000
R= 10,000
R= 3,000
R= 1,000
R= 300
1345
1350
1355
1360
1365
Wavelength (Å)

2 What resolution is needed to measure thermal line widths?

For a collisionally-excited thermal plasma with no turbulence or velocity structure,

- the resolution $R = E/\Delta E$ needed to measure intrinsic line widths (and thus the plasma temperature is $R = 1400\sqrt{(m/T_6)}$ for an emission line with 300 counts.
- For higher S/N one one can get by with slightly lower resolution.
- Photoionization-dominated plasmas have lower temperatures and narrower lines requiring higher resolution.

Ion	Atomic Weight	$\log T_{ion}$	Resolution
O VII	16	6.3	4,000
O VIII	16	6.7	2,500
Ne IX	20	6.6	3,200
Ne X	20	6.9	2,200
Mg XII	24	7.2	1,700
Si XIV	28	7.4	1,500
Fe XVII	56	6.7	4,700
Fe XXV	56	7.8	1,300

3 Warm Absorber Lines in AGN Outflows

Why the study of warm absorber lines in X-rays is important:

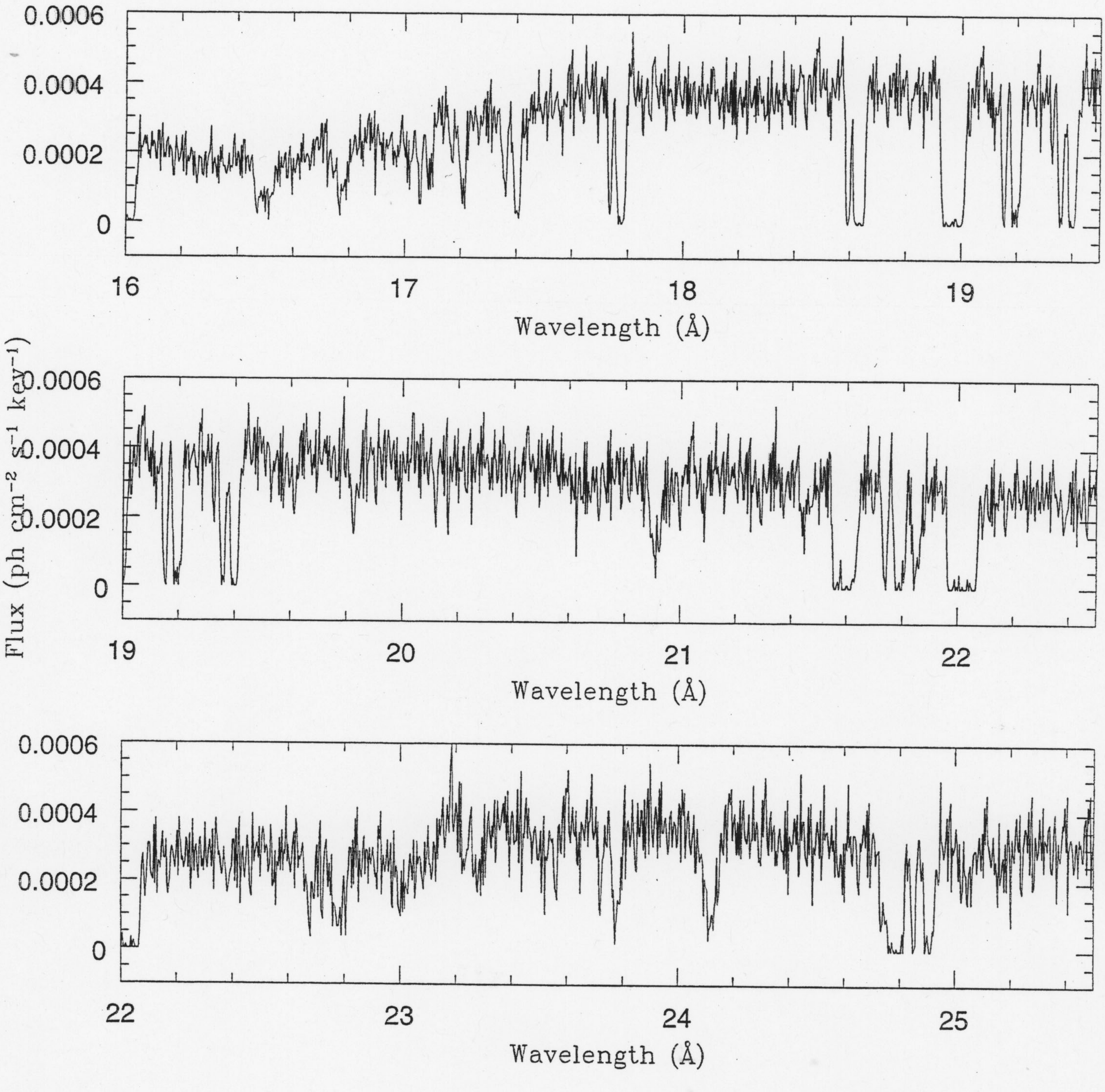
- AGN are powered by accretion, but outflowing matter carries a significant amount of energy, so is important dynamically.
- Highly-ionized, outflowing, low-density matter located close to the broad emission line region produces an absorption line spectrum (warm absorber).
- The warm absorber gas is photoionized producing lines in the X-ray region (e.g., O VII and O VIII) and the UV and FUV (e.g., O VI, C IV, and Ly-α).
- These lines can diagnose the outflowing plasma (ionization, column density, mass flux).

Information content of X-rays and UV:

- The X-ray spectrum best measures the highly ionized phase(s) of the warm absorber, but the lines are unresolved in MEG/HEG data, a very complex spectrum of absorption/emission lines, and many lines are saturated.
- Krongold et al. (ApJ 597, 832 (2003)) analyzed a 900 ks Chandra HETG spectrum of NGC 3783 identifying a single outflow velocity ($\approx$ 750 km/s) with some evidence for a second component seen in O VII but not O VIII.
- They model the warm absorber with a single velocity, 300 km/s turbulent velocity, and two ionization phases.
- UV spectra have $>$ 20 times higher spectral resolution (R $\sim 15,000$ for FUSE and R $\sim 40,000$ for HST/STIS) and can measure smaller column densities.
- FUSE and HST/STIS data identify velocity components for NGC 3783 in O VI, C IV, and Lyman-α lines at 1320, 1027, 724, and 548 km/s.
- But, the UV data best sensitive to the low ionization plasma.

Conclusion:

- If Con-X has R = 3,000 (100 km/s), one can centroid the velocity components and measure column densities for weak lines.
MINIMUM REQUIREMENT
- Simulations at R = 5,000 (60 km/s) show that the strong lines are saturated.
- At R = 10,000 (30 km/s) one can probably measure the line widths with confidence. **GOAL**



Flux (ph cm^{-2} s^{-1} key^{-1})
0.0006
0.0004
0.0002
0
16
17
18
19
Wavelength (Å)
19
20
21
22
Wavelength (Å)
22
23
24
25
Wavelength (Å)

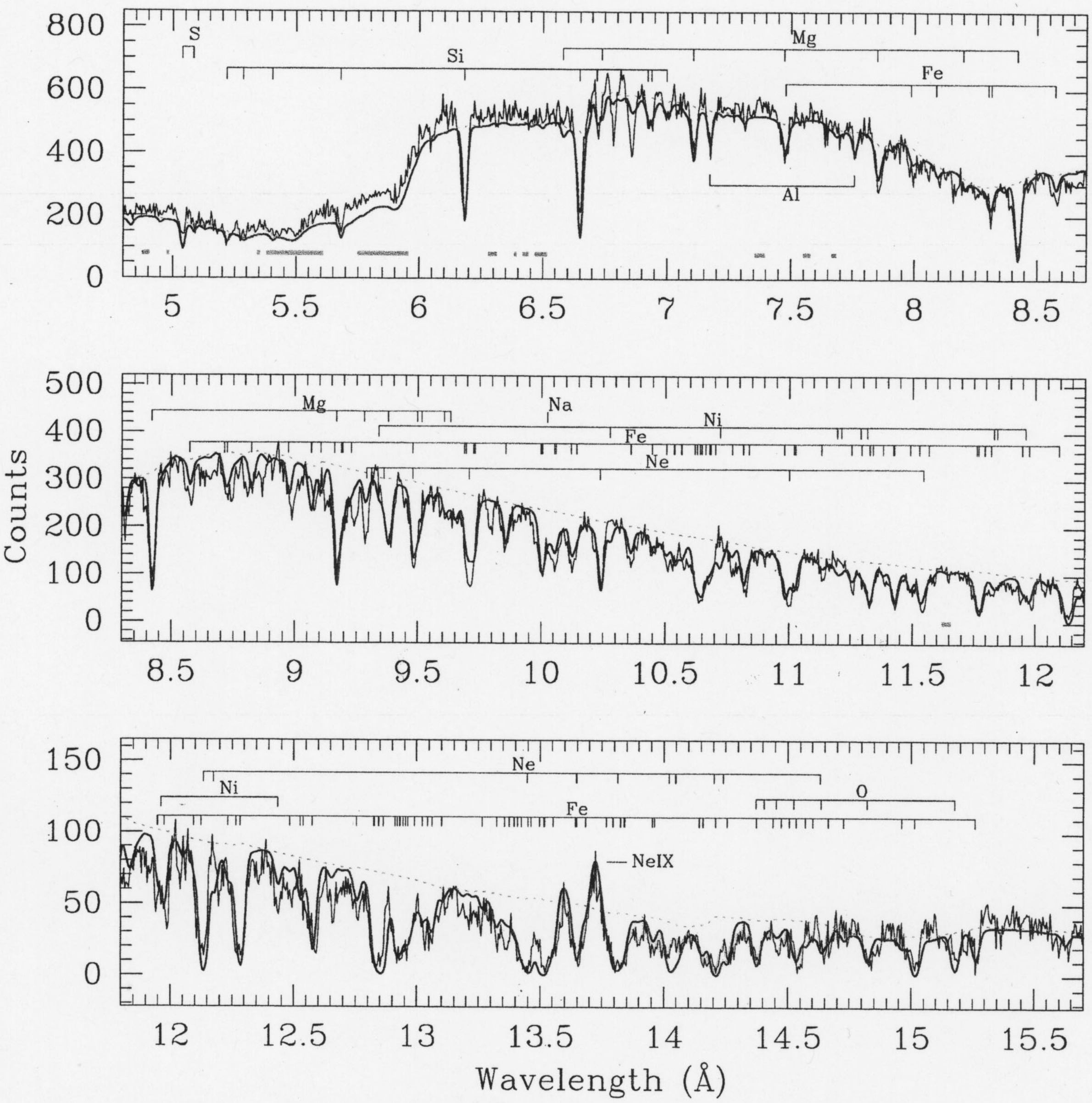


Fig. 3a.— Two phase absorber model plotted against the first-order MEG spectrum of NGC 3783. Absorption lines predicted are marked in the top (red). Single labels stand for emission lines (blue). The line free zones are indicated at the bottom of each panel (green). The continuum level (including edge continuum absorption) is overplotted for comparison (dotted green line). The spectrum is presented in the rest frame system of the absorbing gas.[9]

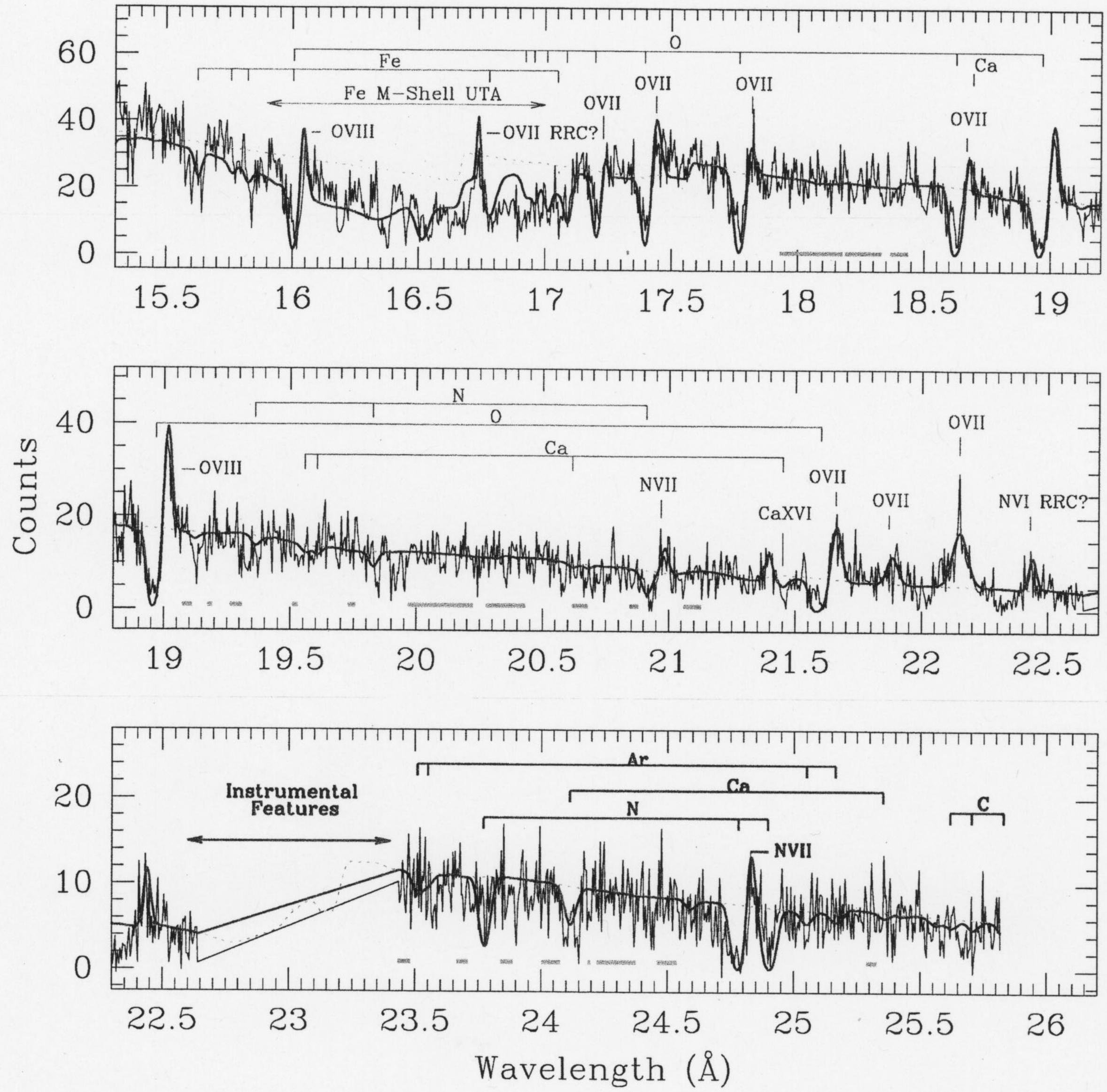
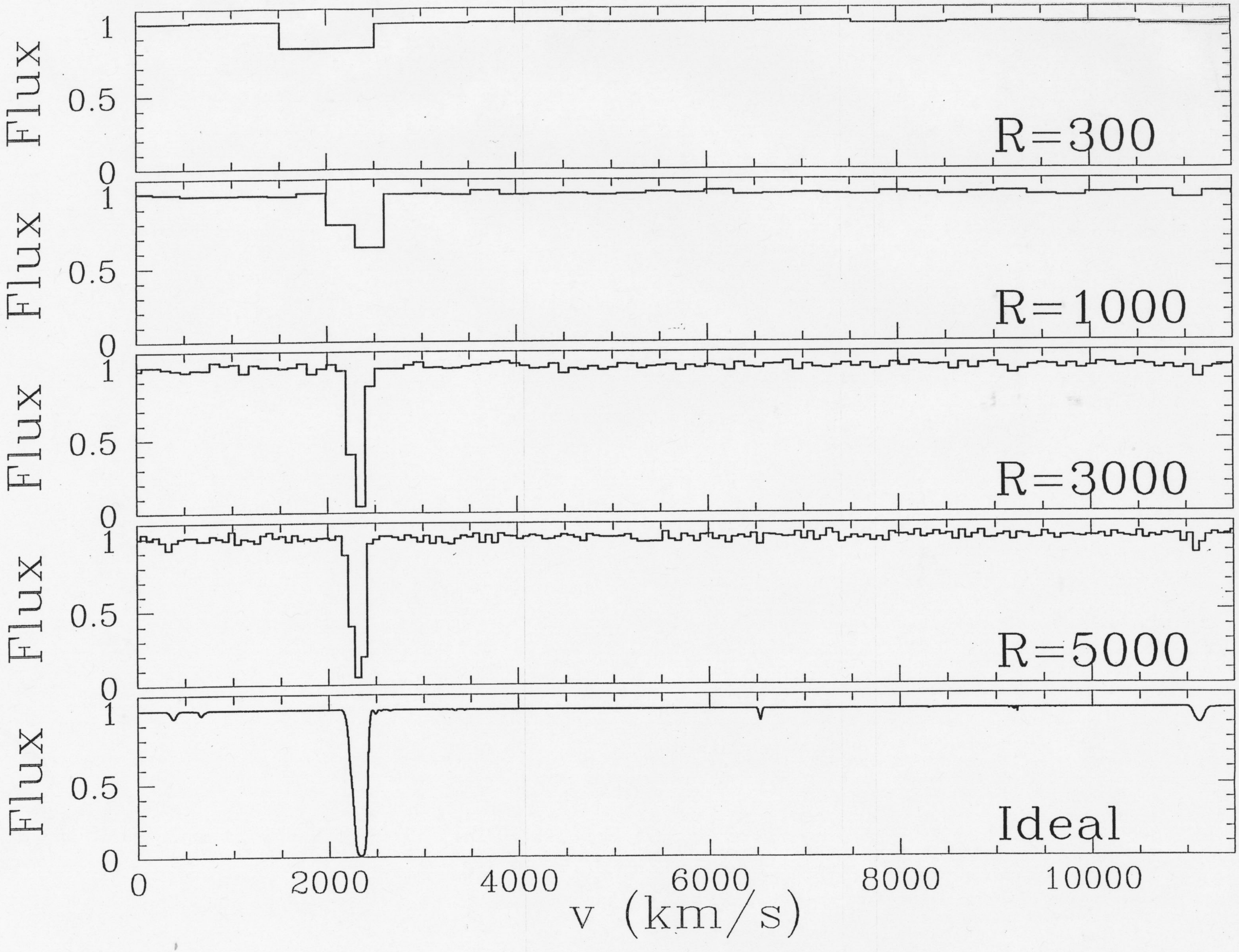


Fig. 3b.— Two phase absorber model plotted against the first-order MEG spectrum of NGC 3783. Absorption lines predicted are marked in the top (red). Single labels stand for emission lines (blue). The line free zones are indicated at the bottom of each panel (green). The continuum level (including edge continuum absorption) is overplotted for comparison (dotted green line).[9]

2 What is the structure of the IGM?

What resolution is needed to characterize the IGM (absorption line fluxes, components, and line widths)?

- Simulation for the O VIII Lyman-α line at 20.02 Å in the direction of PKS 2155-304.
- Continuum flux 0.0033 ph/cm^2/s/Å (Fang et al 2002, ApJ 572, L127).
- Simulation by Nick Gnedin assuming $A_{eff} = 3,000$ cm^2 and an integration time of 50 ks.
- Since the line is saturated, need R = 3,000 to measure the line column density.
- To measure the line width need R = 3,000.



Flux
R=300
Flux
R=1000
Flux
R=3000
Flux
R=5000
Flux
Ideal
0
0.5
1
0
2000
4000
6000
8000
10000
v (km/s)